

# **ANALYSIS OF DATA FROM THE ENERGETIC GAMMA-RAY EXPERIMENT TELESCOPE (EGRET) ON THE COMPTON GAMMA RAY OBSERVATORY**

*A Final Report for Work Completed under Cooperative  
Agreement NCC 5-93 for Research between Hampden-  
Sydney College and the National Aeronautics and Space  
Administration*

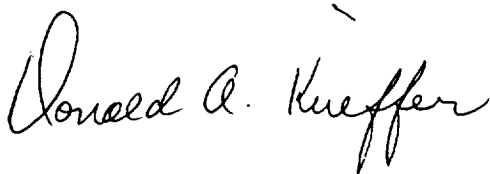
January 15, 1999

Period of the Agreement: August 14, 1996 - August 15, 1998

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Principal Investigator

A handwritten signature in cursive script, reading "Donald A. Kniffen". The signature is written in dark ink and is positioned above the printed name.

Donald A. Kniffen

## **1. Work Proposed under this Cooperative Agreement**

This agreement consists of the following cooperative efforts:

The PI will analyze portions of the EGRET data in conjunction with EGRET Team members from the Goddard Space Flight Center, Stanford University, The Max Planck Institute for Extraterrestrial Physics, and Northrop-Grumman Aerospace Corporation. The PI will participate with the rest of the experiment team in preparation of papers on the results of these analyses which will be published in professional journals and presented at scientific meetings both in the U.S. and elsewhere. The PI will also attend team meetings at the Goddard Space Flight Center and other locations, as scheduled, for the purpose of coordinating activities with the other team members. Finally the PI will participate in the routine review of the data from selected instrument pointings for the purpose of reviewing instrument performance and monitoring known sources and searching for new ones as part of the responsibility for archiving the data and maintaining an overall EGRET catalog.

Specifically the cooperative activities for the coming year include in addition to the regular and routine functions outlined above the following specific activities:

- The completion of analysis of data, in cooperation with the EGRET Principle Investigator and the other Co-Investigators, on the source previously known as 2CG 135 and now listed in the second Egret Catalog as 2EG J0241 + 6119.
- Preparation of a manuscript in cooperation with the EGRET PI and other members of the EGRET Team on the spectral and temporal variations of 2EG J0241 + 6119.
- Continuation of the analysis, in cooperation with the EGRET PI and other members of the EGRET Team, of the high latitude diffuse gamma radiation believed to be extragalactic in origin. This analysis will include a search for spatial fluctuations in the emissions in an attempt to understand the nature of the radiation.
- The continued analysis in cooperation with the EGRET PI and other members of the EGRET Team of selected viewing periods for the purpose of providing an uniform analysis of the sky and for the continued monitoring of the instrument performance.
- Participation in team meetings at the locations selected by the organizers of the meeting for the purpose of planning the activities of the team.
- Other activities in cooperation with the EGRET PI and other members of the EGRET Team as the need arises to assure the continued optimum operation of the EGRET instrument on orbit and the smooth data analysis flow.

## 2. Work Accomplished under this Cooperative Agreement

The Energetic Gamma Ray Experiment Telescope (EGRET) on the *Compton* Gamma Ray Observatory (CGRO) has made many major discoveries. Prior to EGRET, only one object had been seen outside our Milky Way Galaxy in high-energy  $\gamma$ -rays. This is the superluminal quasar 3C273 (Superluminal means there are blobs seen emitted from the quasar that appear to be moving faster than the speed of light. This is an illusion.). In an early observation with the EGRET instrument, shortly after the launch of CGRO, the quasar 3C 279 was seen in a flaring state ( Hartman, et al. *ApJL* **385**, L1,1992). The source was observed to vary on a time scale as short as one day ( Kniffen, et al. *ApJ* **411**, 1993 ) indicating a relatively localized emission region, probably a Black Hole. This variability is shown the figure below. Over 50 AGN (Active Galactic Nuclei), all flat spectrum radio sources (FSRSs), have been identified in gamma-rays with EGRET. FSRSs are sources seen in the radio frequency of the electromagnetic spectrum which display remarkably similar amounts of brightness across the radio wavelengths. Collectively they belong to the class of objects known as blazars, which includes quasars and BL Lacs, the most highly time-variable of all known external galaxies. As at other wavelengths, time variability in their  $\gamma$ -ray emission is a major feature of these objects ( v. Montigny, et al. *ApJ* **440**, 525, 1995, Mukherjee, et al., 1997, work in progress ), as are their relatively flat spectra in the gamma rays, as well. These characteristics are sufficiently persistent that at least some of the unidentified sources displaying similar characteristics are possibility also blazars.

One of the major outcomes of the earlier European COS-B high-energy gamma-ray satellite mission was the second COS-B (2CG) catalog ( Swanenburg, et al., *ApJ* **243**, L69, 1981 ) listing 25 discrete gamma-ray sources detected with COS-B. There were questions raised about the nature of some of these sources by Pollack, et al. ( *A&A* **162**, 352, 1985 ) and by Mayer-Hasselwander and Simpson ( *Proc. XX1st ICRC* **1**, **338**, 1985) who showed that all but a few sources were consistent with enhancements in the gas density along the line of sight in the direction of the claimed source. Some additional sources were suggested.

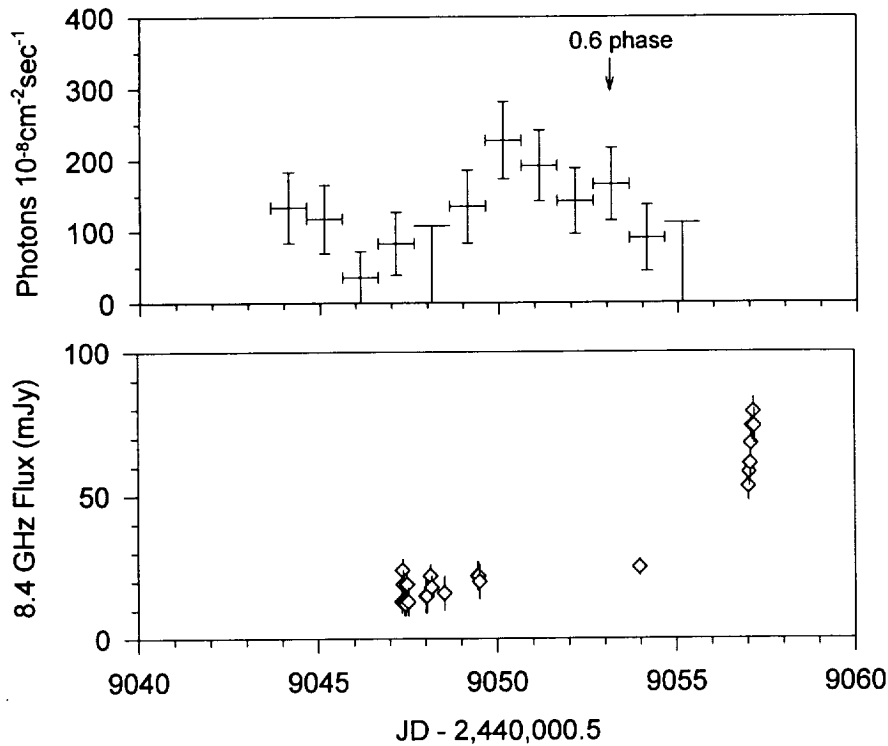
The uncertain nature of the 2CG sources and the mostly unsuccessful attempts to find counterparts at other wavelengths made their study one of the major objectives of the EGRET instrument on the *Compton* Gamma Ray Observatory. The Second EGRET Catalog ( Thompson, et al., *ApJS* **101**, 259, 1995 ) lists 71 sources seen by EGRET but not identified with sources seen at other wavelengths. 11 of the COS-B catalog sources were confirmed by EGRET. These included all of the ones which survived the more critical analyses cited above.

The number of sources now known allows class studies even when identifications of the individual sources have been unsuccessful. Early studies have suggested that there is more than one class ( Mukherjee, et al. *ApJL* **441**, L61, 1995 ; Ozel and Thompson 1966 **463**, 405, 1996; McLaughlin, et al. *ApJ*, 1996, in press ; Merck, et al. *A&AS*, 1996, in press ) . The largest single class of identified  $\gamma$ -ray sources lying within our Milky Way is radio pulsars. EGRET results have extended the class from two to six, with the possibility of one other. The source Geminga is

definitely a pulsar (A pulsar is technically a pulsating radio source.), though it has yet to be seen in the radio despite extensive searches. The pulsed emission was discovered in X-rays (Halpern and Holt, *Nature* **357**, 222, 1992 ) and confirmed in gamma-rays ( Bertsch, et al. *Nature* **357**, 307, 1992 ; Mattox, et al., *ApJL* **401**, L23, 1992 ) . The total number of pulsars identified with EGRET is consistent with the prediction of Bailes and Kniffen ( *ApJ* **391**, 659, 1992 ) based on a model for the birth and evolution of pulsars. This model will be reexamined based on the details of EGRET observations and newer pulsar surveys in an attempt to refined the estimate of the contribution of unresolved  $\gamma$ -ray pulsars to the diffuse galactic gamma-ray emission. Spectral differences between the pulsars and the galactic diffuse emission imply pulsars cannot account for more than about 20 to 30 percent of the galactic diffuse high-energy gamma-ray glow. Another characteristic of pulsars is their lack of time variability on a time scale of days to weeks. This distinguishes them from most other gamma-ray sources, include the unidentified sources.

The class studies indicate that many of the properties of the unidentified sources are quite different from pulsars including their distribution with galactic latitude ( Mukherjee, et al. *ApJL* **441**, L61, 1995 ), their spectral indices ( Ozel and Thompson 1966 **463**, 405, 1996), and their time variability ( McLaughlin, et al. *ApJ*, 1996, in press ) .

The study I undertook during my the period of the Cooperative Agreement focused on the time variability. The study cited above and others currently in progress use the fluxes averaged over two weeks or several days at a minimum, a typical exposure period for The *Compton* Observatory. While the results do reach the interesting conclusion that the unidentified sources typically are more highly variable on a long time scale than the gamma-ray pulsars, the time variable sensitivity of EGRET leaves the quantitative results in question. However, what has not been examined is the short, one-day, variability. Such a study has led to interesting results in the case of the 2CG 135+01 source first listed in the COS-B catalog. Believed to be associated with the elliptical binary radio source LSI +61° 303, this source is quite variable in high energy gamma-rays on both the two week and one day time scales. This source is listed as 2EG 0241+6119 in the Second EGRET Catalog. More recently, the source has been listed in the Third EGRET catalog as 3EG J0241+6103 (Hartman, et al., 1999). While no correlation with radio variability could be claimed (Kniffen, et al., submitted, 1997), this is a new class of gamma-ray source. Are there more? The short-term time variability is one indicator which can be used along with spectral shape and hardness to identify members of this class. The time variability of the  $\gamma$ -ray emission for 2EG 0241+6119 is shown in the upper portion of the figure below. Simultaneous 8.4 GHz data from the Madrid Deep Space Network are shown in the lower portion. The evidence for simultaneity is inconclusive.



The short-term time variability is a very major effort since it does not involve standard maps of the EGRET data. Maps must be generated for the shorter time periods appropriate to the source under investigation. The standard EGRET analysis software will be used in this study following procedures developed for the analysis of the interesting . COS-B source 2CG135+01, which lies in our Milky Way. Two papers on this work were published in the *Astrophysical Journal* (Kniffen, et al., *ApJ* **486**, 126, 1997; Tavani, et al., *ApJL* **497**, L89, 1998) during the period of this agreement. No new observations were needed for the work. The sources selected were the unidentified sources between  $-20^\circ \leq b \leq 20^\circ$  in galactic latitude which have at least a  $5 \sigma$  significance in one or more viewing period. This yielded 24 galactic sources for which one-day fluxes were derived.

Another aspect of temporal studies that has received little attention is the variability at other energies other than the  $\geq 100 \text{ MeV}$  fluxes. While this further restricts the number of sources available for study, it will be pursued for the few sources that provide sufficiently high fluxes to give a meaningful result. This may provide useful information for diagnosing the nature of the sources. This work is still in progress.

Additional work is planned for the coming year. For sources that appear similar in their variability and other attributes such as spectral behavior, an intense search for counterparts will be conducted. It is envisioned that existing catalogs and archived data sets will be adequate for this study, but where they are not multi-wavelength observations will be arranged.

This work will complement work by others to provide the most information possible to address one of the major original objectives of EGRET, characterizing and identifying the unidentified sources. This will be a major thrust over the next two years.

Unfortunately a major problem was discovered in the process of the analysis. Variability in the response of the instrument was uncovered that compromises the ability to examine true source variability. This problem has required a program to reanalyze the entire database used for the study. This is a massive effort and it is still underway with the help of Dr. Paul Wallace who was a temporary member of our department at Hampden-Sydney College and is now at Berry College near Rome, Georgia. This reanalysis will take another year because of my academic responsibilities and those of Dr. Wallace. However, this is very important work not just for this project, but also for many others being done by other scientists using EGRET data. The result will be a methodology for excluding the effects of variability in the performance of the EGRET instrument in the analysis of source variability in the entire 7 year EGRET database.

A Preliminary report on the reanalysis was given at the semi-annual meeting of the American Astronomical Society in San Diego, California in June 1998. This work and travel was supported under a Summer Faculty Fellowship, and is discussed in a separate report on that activity.

### **3. Presentations and Publications During the Agreement Period Year**

#### Publications:

1. 1997 "EGRET Observations of the Gamma-Ray Source 2EG J0241+6119," D.A. Kniffen, W.C.K. Alberts, D.L. Bertsch, B.L. Dingus, J.A. Esposito, C.E. Fichtel, R.C. Hartman, S.D. Hunter, G. Kanbach, Y.C. Lin, J.R. Mattox, H.A. Mayer-Hasselwander, P.F. Michelson, C. von Montigny, P.L. Nolan, E.J. Schneid, P. Sreekumar and D.J. Thompson, *Astrophys. J.* (Submitted)
2. 1997 "Comparison of X-Ray and Radio-Selected BL Lacertae Objects in High-Energy Gamma-Ray Observations," Y.C. Lin, D.L. Bertsch, B.L. Dingus, J.A. Esposito, C.E. Fichtel, R.C. Hartman, S.D. Hunter, G. Kanbach, D.A. Kniffen, J.R. Mattox, H.A. Mayer-Hasselwander, P.F. Michelson, C. von Montigny, R. Mukherjee, P.L. Nolan, E.J. Schneid, P. Sreekumar, D.J. Thompson and T.D. Willis, *Astrophys. J. Lett.* **476**, L11.
3. 1997 "Cygnus X-3 and EGRET Gamma-Ray Observations," M. Mori, D.L. Bertsch, B.L. Dingus, J.A. Esposito, C.E. Fichtel, S.D. Hunter, G. Kanbach, D.A. Kniffen, Y.C. Lin, J.R. Mattox, H.A. Mayer-Hasselwander, P.F. Michelson, C. von Montigny, R. Mukherjee, P.L. Nolan, P.V. Ramanamurthy, E. Schneid, P. Sreekumar and D.J. Thompson, *Astrophys. J.* **476**, 842.

4. 1997 EGRET Observations of the Diffuse Gamma-Ray Emission from the Galactic Plane," S.D. Hunter, D.L. Bertsch, J.R. Catelli, T.M. Dame, S.W. Digel, B.L. Dingus, J.A. Esposito, C.E. Fichtel, R.C. Hartman, G. Kanbach, D.A. Kniffen, Y.C. Lin, H.A. Mayer-Hasselwander, P.F. Michelson, C. von Montigny, R. Mukherjee, P.L. Nolan, E. Schneid, P. Sreekumar, P. Thaddeus, and D.J. Thompson, *Astrophys. J.* **481**, 205.
5. 1997 Multiwavelength Observations of 3C273 in 1993-95," C. von Montigny, H. Aller, M. Aller F. Bruhweiler, W. Collmar, T.J.-L. Courvoisier, P.G. Edwards, C.E. Fichtel, A. Fruscione, G. Ghisellini, R.C. Hartman, W.N. Johnson, M. Kafatos, T. Kii, D.A. Kniffen, G.G. Lichti, F. Makino, K. Mannheim, A.P. Marsher, B. MCBreen, I. McHardy, J.E. Pesce, M. Pohl, E. Ramos, W. Reich, E.I. Robson, K. Saski, H. Teräsranta, M. Tornikoski, C.M. Urry, E. Valtaoja, S. Wagner, and T. Weekes, *Astrophys. J.* **483**, 161.
6. 1998 "The Variable Gamma-Ray Source 2CG 135+01," M.Tavani, D. Kniffen, J.R. Mattox, J.M. Paredes, and R.S. Foster, *Astrophys. J.* **497**, L89.
7. 1998 "Egret Observations of the Extragalactic Gamma-Ray Emission," P. Sreekumar, D.L. Bertsch, B.L. Dingus, J.A. Esposito, C.E. Fichtel, R.C. Hartman, S.D. Hunter, G. Kanbach, D.A. Kniffen, Y.C. Lin, H.A. Mayer-Hasselwander, P.F. Michelson, C. von Montigny, A. Mücke, R. Mukherjee, P.L. Nolan, M. Pohl, O. Reimer, E. Schneid, J.G. Stacy, F.W. Stecker, D.J. Thompson, and T.D. Willis, *Astrophys. J.* **494**, 523.
8. 1998 "Egret Observations of High-Energy Gamma-Ray Emission from Blazars: An Update," R. Mukherjee, D.L. Bertsch, S.D. Bloom, B.L. Dingus, J.A. Esposito, C.E. Fichtel, R.C. Hartman, S.D. Hunter, G. Kanbach, D.A. Kniffen, Y.C. Lin, H.A. Mayer-Hasselwander, L.M. McDonald, P.F. Michelson, C. von Montigny, A. Mücke, P.L. Nolan, M. Pohl, O. Reimer, E.J. Schneid, P. Sreekumar, and D.J. Thompson, *Astrophys. J.* **490**, 116.

#### 4. Continuing Work

As indicated above, the work continues. This has been a very productive agreement and the Principal Investigator appreciates the opportunity to participate in this most important NASA scientific program.